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DEPARTMENT OF PSYCHOLOGY
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A METHODOLOGICAL STUDY OF ELECTRONICS TROUBLE SHOOTING SKILL: I. RATIONALE FOR AND DESCRIPTION OF THE MULTIPLE-ALTERNATIVE SYMBOLIC TROUBLE SHOOTING TEST

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Principal Investigator

William W. Grings

Project Director

Joseph W. Rigney

Research Assistants

Nicholas A. Bond

Stanley A. Summers

DEPARTMENT OF PSYCHOLOGY

UNIVERSITY OF SOUTHERN CALIFORNIA

PREFACE

This report is the ninth in a series published by the Electronics Personnel Research group. The first seven were based on shipboard observation of electronics personnel aboard ships of the destroyer class. The eighth, ninth, and tenth reports describe the results of collateral research which was done concurrently with this shipboard observation. Their subject matter will differ from that of the first seven reports; consequently their titles are listed below, with a brief description of their contents.

8. A Comparison of the Effects of Four Display Conditions on the Discrimination Learning of Simulated Sonar Echo-Returns.

   A report of the results of a laboratory study of discrimination learning, employing stimulus patterns of short duration, presented by means of aural, visual, and combined aural-visual displays.

9. A Methodological Study of Electronics Trouble Shooting Skill: I. Rationale for and Description of the Multiple-Alternative Symbolic Trouble Shooting Test.

   A description of a new type of test format designed for measuring some aspects of trouble shooting skill, and a discussion of the conception of trouble shooting on which it is based.

10. A Methodological Study of Electronics Trouble Shooting Skill: II. Intercomparisons of the MASTS Test, a Job-Sample Test, and Ten Reference Tests Administered to Fleet ETs.

    A report of the results of the administration of two forms of the MASTS Test, its progenitor job-sample test, and a battery of achievement and ability oriented reference tests to a sample of ETs from ships undergoing repairs in the Long Beach Naval Shipyard.

ACKNOWLEDGMENTS

The research reported in this series reflects the contribution of a large number of persons within the Military Establishment. Grateful appreciation for this assistance is extended to the Cruiser Destroyer Force, Pacific; the Training Division and the Personnel Analysis Division, Bureau of Naval Personnel; the Personnel and Training Branch of the Psychological Services Division of the Office of Naval Research; and the Electronics Coordinator's Section of the Office of the Chief of Naval Operations.

The cooperation of the Commanding Officer, and of Mr. J. Wesley Johnson, Superintendent of Training, Long Beach Naval Shipyard, in permitting field work to be done there, and in providing testing space, is especially appreciated.

Mr. William Hickman, Training Division, Long Beach Naval Shipyard, devoted many hours of his own time to orienting two of the project personnel in electronics and in acting as a technical consultant. His contribution is gratefully acknowledged.

Mr. John R. Hills, half-time research assistant, contributed materially to the collection of problem information and to the planning of the new test format. Harold R. LaPorte and Donald W. Svenson served at different times as liaison men between ship personnel, the testing room, and the Electronics Personnel Research Offices.

ABSTRACT

This report is one of two concerning a new type of test format which was a product of a methodological study of electronics trouble shooting. A conception of trouble shooting is set forth as it is related to problem solving in general, and as it is exemplified in electronics situations. The test format is described in detail, and the pertinent aspects of its subject matter, relation to other trouble shooting situations and tests, and alternative scoring parameters are discussed.

TABLE OF CONTENTS

LIST OF FIGURES

LIST OF PLATES

A METHODOLOGICAL STUDY OF ELECTRONICS TROUBLE SHOOTING SKILL: I. RATIONALE FOR AND DESCRIPTION OF THE MULTIPLE-ALTERNATIVE SYMBOLIC TROUBLE SHOOTING TEST

I. INTRODUCTION

This report contains a description of the Multiple-Alternative Symbolic Trouble Shooting Test and the rationale underlying its development. The test is a result of a methodological study of the problems inherent in the measurement of trouble shooting skill. Conventional paper-and-pencil tests may be ill-suited to this purpose. They are most useful for measuring knowledge presumably related to or necessary for performance. However, their format generally is too inflexible for eliciting adequate samples of a performance. Conventional job-sample tests, on the other hand, evoke performance assumed to be representative of that on the job by the use of actual equipment. But the administrative inconvenience and expense of equipment tests is a serious practical disadvantage. So is the fact that they are inherently difficult to score.

The MASTS test was developed as a new kind of test format representing the complexities of the trouble shooting situation with sufficient realism to evoke trouble shooting performance, while possessing some of the administrative convenience of a paper-and-pencil format. It uniquely combines these characteristics:

1. It forces the subject to determine his own path to the solution of a trouble shooting problem. No standard list of alternatives is presented for him to follow.

2. The discrimination of "yes/no" or "in tolerance/out of tolerance," is not made for the subject with respect to the problem information. He has to make these discriminations for himself.

3. The problem information was empirically determined. There are no theoretical values, which so often differ from readings obtained from the actual equipment.

4. An extremely large amount of information is available for each trouble shooting problem. The subject has to find cues to solution of a problem in a pool of approximately five hundred different readings.

5. It is possible to record a detailed protocol of the subject's behavior in the test: the sequence of his responses, the points in the circuit at which he samples information, the number of times he refers to the schematic, and the time of occurrence of these responses can be recorded on a standard form by means of a coding system. These response records provide the basis for studying differences in technique between successful and unsuccessful subjects.

A later report will contain the results of administering this test, a job-sample test, and a battery of reference tests to a sample of ETs from ships undergoing repairs at the Long Beach Naval Shipyard.

II. THE BASIS OF THE MASTS TEST

This section contains a discussion of the job analysis done preliminary to construction of the test. Out of this analysis came the conception of electronic trouble shooting from which the test format was evolved.

A. Trouble Shooting and Electronic Circuits

Observation of ETs performing corrective maintenance aboard destroyers operating off the Pacific Coast, study of trouble shooting in

the University laboratory, and consideration of reports from other investigators provided a background of experience fundamental to development of the test.

The situation in which trouble shooting occurs has two prominent elements, an individual or individuals, and a malfunctioning system.[1] It is the task of the individual (s) to fix the system. Attempts to find what is causing the malfunctioning are called trouble shooting behavior, which is viewed here as a specific kind of problem-solving activity.

Certain elements of the interaction between the individual and the system are common requirements of successful trouble shooting: the individual must (1) have some knowledge of how the system functions normally, (2) obtain information about the current state of the system, (3) relate the information he gets to his conception of the normal system, his past experience with malfunctions of this or similar systems, and his theoretical knowledge of functional relationships embodied in the system, and (4) formulate and test hypotheses as to the most probable cause(s) of the malfunction.

The characteristics of the system and the complexity of the cause(s) of the malfunction are principal determinants of the difficulty of the trouble shooting task. Electronic circuits possess some characteristics peculiar to them. Most of these stem from the simple fact that the electron is invisible. Except at a few isolated spots in the circuit where information carried by it is translated

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[1] The system may be an electronic circuit, an internal combustion engine, a social institution, or a business procedure.

into sensory terms by an output device, the stream of electrons flowing in the equipment, and the complex functional interaction of its parts, are abstract concepts. A wire with a potential of 10,000 volts looks just like a wire with no voltage at all.

This attribute of functional invisibility places certain demands on the trouble shooter in electronics. These, while probably not unique, are believed to have a prominent place in the constellation of subtasks which compose this trouble shooting. It requires him to know and to interrelate two different representations of a circuit - a theoretical conception made up of abstract concepts and based on a schematic; and its actual physical translation in the form of the extremely complicated arrangement of leads, tubes, capacitors, resistors, etc., composing electronic equipment.[2]

The trouble shooter is required to shift back and forth from one representation to the other; he is guided by abstract concepts on the symbolic level while using tools and test instruments at the physical level. As a result, he tends to build up for himself a functional visualization of the circuit embodied in a particular piece of equipment with which he has contact - a functional conceptionalization which is a product of the shifting from one representation of the circuit to

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[2] Not the least of the many troublesome differences between these two representations are the facts that the layout of components in the equipment never corresponds to the spatial arrangement of their symbols on the schematic; and the differences between computed values at points in a theoretical circuit and the actual values at corresponding points in equipment based on that circuit may be considerable, owing to interactions between component tolerances, slight line voltage fluctuations, slightly weak components, and the effects of test instruments on circuit values.

the other while trouble shooting.

B. Analysis of the Trouble Shooting Task in Electronics

On the premise that trouble shooting in electronics merely is a specific example of a general class of trouble shooting behavior, its analysis can follow the frame of reference established by the four requirements which were listed for trouble shooting.

1. Knowing the Normal System. The ET or other technician brings to the trouble shooting situation an accumulation of knowledge about electronic systems which he has picked up from various sources.[3] In addition, he is given a certain amount of information in the form of schematics, photographs, and other reference material accompanying the equipment, such as tables of normal plate voltage readings and the values of circuit components.

2. Getting Information About the Present State of the System. There are two general categories of this information: cues immediately available to the unaided senses and cues which must be transformed into sensory stimuli by an intermediate instrument. Examples of the former are front panel indications, output symptoms,

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[3] It should be pointed out here that some ETs apparently are able to perform corrective maintenance on a specific piece of equipment with which they have had long experience, on the basis of probability of recurrence of a particular symptom-cause relationship which has occurred repeatedly in the equipment's past history. The extreme form of this is not regarded as trouble shooting, since it does not involve problem solving. The ET merely repeats a sequence of operations which have in the past, under similar circumstances, put the equipment back on the air. An example of this type of corrective maintenance was noted on a destroyer, where a leak in the overhead allowed water to drip into a transmitter at rather frequent intervals. Until the deck above was fixed, the ETs immediately replaced the same parts in the transmitter every time it was reported down, without even bothering to check symptoms.

cold tubes, leaking capacitor cans, smoking resistors, etc. Examples of the latter are voltage readings, waveforms, ring time, etc. The devices which perform the transformation are test instruments, and use of such instruments is an important part of the trouble shooting task.

To get information about the present condition of the equipment, then, the technician may perform a careful preliminary search for cues immediately available to his senses, or he may resort to auxiliary devices to sample information at various points in the circuit. Both of these procedures involve three steps: (a) choice of the information-sampling device or process, (b) selection of points in the circuit at which to sample information, and (c) correct use of the chosen information-sampling device or process.

3. Relating Information About the Present Condition of the System to a Conception of Its Normal Condition. The trouble shooter has to do something with the information he gets by his sampling processes. As he collects it, he necessarily attempts to classify it by computing what the functional values at particular points theoretically should be, or by comparing the readings he had taken with a list of values supplied in supplementary reference material, or by comparing them with standards based on his experience with the particular equipment. All of these processes are based on: (d) the discrimination of usual or unusual for each bit of information collected from the equipment by a sampling process.

4. Checking Possible and Probable Causes of the Malfunction. So far, the processes described are relatively straightforward applications of observational techniques to a malfunctioning system. By

themselves, they might result in the accumulation of a large sample of problem information. However, unless this information were integrated into a cause-effect frame of reference, it would be insufficient for solving the trouble-shooting problem.

Another level of the behavior begins some time before or during the application of these techniques, and goes on concurrently with them. At some stage in the task, the trouble shooter begins to formulate hypotheses as to the possible and probable causes of the malfunction. The basis for this formulation may be the relationships he draws between the information he collects and his functional conceptualization of the equipment.[4]

To be an efficient or even a successful trouble shooter, the technician must avoid either the extreme of getting all the information potentially available or of rebuilding an electronic system component by component. He must achieve some economical balance between information sampling, and the risk that his informed guesses as to causes of patterns of unusual information will be wrong. Generally, he achieves this balance by selecting the points at which he samples circuit information in such a way that he can eliminate portions of the equipment as possible *loci* of the trouble each time he

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[4] However, a trouble shooter does not necessarily have to sample information first. It is possible for him to make random guesses about the cause of a failure in a system and to be correct some times. The more complicated the system, the greater the number of possible causes of failure, and the less is this guessing apt to be successful. Conversely, the more a trouble shooter knows about the present condition of the system in relation to its normal condition, the more are his informed guesses apt to be correct, provided he can deduce cause-effect relationships for the discrepancies he notes.

does the sampling. This narrowing of the field of possible causes permits the technician to check a smaller number of alternative probable causes, one or more of which will be the real source(s) of the malfunction.

This elimination of possible and probable causes is conceived of as a product of the first three requirements discussed above, and this fourth requirement, which includes these steps: (e) integration of the information as it is collected into a cause-effect frame of reference, and (f) testing hypotheses as to probable causes of the trouble.

C. Implications for Test Construction

This discussion of trouble shooting is intended to suggest certain conclusions about the nature of trouble shooting behavior which have served as the underlying assumptions of the MASTS Test. It is not implied the analysis represents the way all ETs trouble shoot, for at least some technicians do not follow a system, and cannot verbalize the structuring principles of their behavior in this situation.

The analysis does show, however, that the trouble shooting task is composed of heterogeneous subtasks, each requiring certain activities which are determinants of the success or failure of the trouble shooting effort.

It is important to emphasize that the technician has to structure the problem for himself. He starts with a certain number of "givens" in the situation; output symptoms, front panel indications, operator reports, supplementary reference material, and his own experience. Between this start and the end of the problem lies a solution route which he determines. It may have numerous byways, or it may proceed by the

shortest possible path from start to successful solution of the problem. The point to reiterate is that this path is a result of the interaction between the situation and the individual. No two technicians solve the same problem in exactly the same way. There are no fixed alleys in the "maze" they traverse. Each individual selects his own test points in the circuit and is faced by his own choice points, each of which is a resultant of some of his behavior up to that time.

This conception rejects the view that the trouble shooter's successive responses are rigidly determined by his preceding responses. Analysis of detailed response records has shown that even the successful trouble shooter makes both fruitful and unfruitful moves. He may indulge in repetitive behavior, making the same measurement over and over at a test point. Or, he may skip about in the circuit with no apparent relationship among his responses. The idea that the first response determines what the second response will be, and that one and two determine the nature of the third, presents too rigid a picture of the process.

It may be that this idea would tend to be more and more applicable as the efficiency of the trouble shooters increased, but a test which forces all subjects to choose the same alternatives at the same choice points would omit an important source of variance. A technician's fruitful responses move him closer to a solution, and in that sense are successively dependent, but this relationship holds only among certain responses often separated by trial and error behavior.

Conventional paper-and-pencil test formats are inadequate for presenting realistic trouble shooting problems to a subject. They tend to rigidly structure the technician's path from beginning to finish by supplying a very limited number of standard alternatives, choice points, and samples of problem information, and they give away information by listing alternatives and crucial cues.

The ideal format for a measure of trouble shooting behavior would start the subject with a standard minimum of information about a problem and then force each subject to structure his own presolution behavior. It would require the subject to use the processes which have been discussed in the analysis of electronics trouble shooting, and which are summarized here:

1. Knowing the Normal System

2. Getting Information About the Present State of the System

    a. Choice of the information-sampling device or process.
    b. Selection of points in the circuit at which to sample information.
    c. Correct use of the chosen information-sampling device or process.

3. Relating the Information About the Present Condition of the System to a Conception of Its Normal Condition

    d. The discrimination of usual or unusual for each bit of information collected from the equipment by a sampling process.

4. Checking Possible and Probable Causes of the Malfunction

    e. The integration of the information as it is collected into a cause-effect frame of reference.
    f. The testing of hypotheses as to probable causes of the trouble.

This conception required a new kind of test format. After a considerable amount of preliminary analysis, the structure of the Multiple-

Alternative Symbolic Trouble Shooting Test was developed. The remainder of the paper will be devoted to a description of its format and a discussion of its characteristics.

III. DESCRIPTION OF THE MASTS TEST

The important characteristics of the MASTS Test will be described in this section. The present physical form of the test is regarded merely as one possibility for the embodiment of its principles. The exploded drawings in Figs. 1 and 2, and the photographs (Plate I) accompanying the text give the reader structural details of the current form.

A. The Test Format

The general requirements listed in the preceding section imply either a job-sample test or some arrangement which would replace both the electronic equipment and the test instruments in the trouble shooting situation, while reproducing a sufficient number of the subtasks in it to evoke representative trouble shooting behavior. To accomplish this, the test should provide the subject with a pool of information about each problem which he can sample according to his own inclinations. The test also should possess face validity and interest; it should make the subject *feel* that he is trouble shooting.

The apparatus which was built is shown in Fig. 1. The following discussion refers to the numbered parts of this drawing. This is the laboratory model of the test. A production model could be reduced in size and weight and some other refinements could be introduced.

The masonite backboard (1) acts as a support in the current model. It is approximately 4 x 5 feet. Along the bottom edge, grooved strip (A) serves to hold the ends of the five panels in place.

The pool of problem information is typed on the sheet (2). There is a different sheet for each problem. For the sake of convenience in typing and handling, this sheet has been made in five strips, each fitting under one panel. The information is typed on the strips in circles, which were drawn by running a pencil around the holes in the superimposed panels (3).

The problem information presented to the subject is of three classes: readings made at test points in the circuits which were chosen as contexts for the trouble shooting problems, information which would be obtained from manipulating front panel controls and screwdriver adjustments on actual equipment, and the answers to the problems. These three classes of information will be described more fully later.

The five panels (3) are masonite. Their bottom ends fit under the strip (A) on (1). The top ends of the panels are clamped to (1) by aircraft rigger's clamps (B). In these panels are drilled 3/4" holes. On each of four panels there are five columns and 25 rows of these holes. On the fifth panel, there are seven columns of holes, one column for "vary" information and six for the "answer" section of the test. Each hole in the panels is "stoppered" with a cork (Fig. 2). In the first four panels, all the corks in a particular one of the five columns per panel are painted a distinctive color. The small strips (C) contain the labels for the columns of corks. Every strip has the same five labels, one for each of the five columns on a panel. These labels correspond

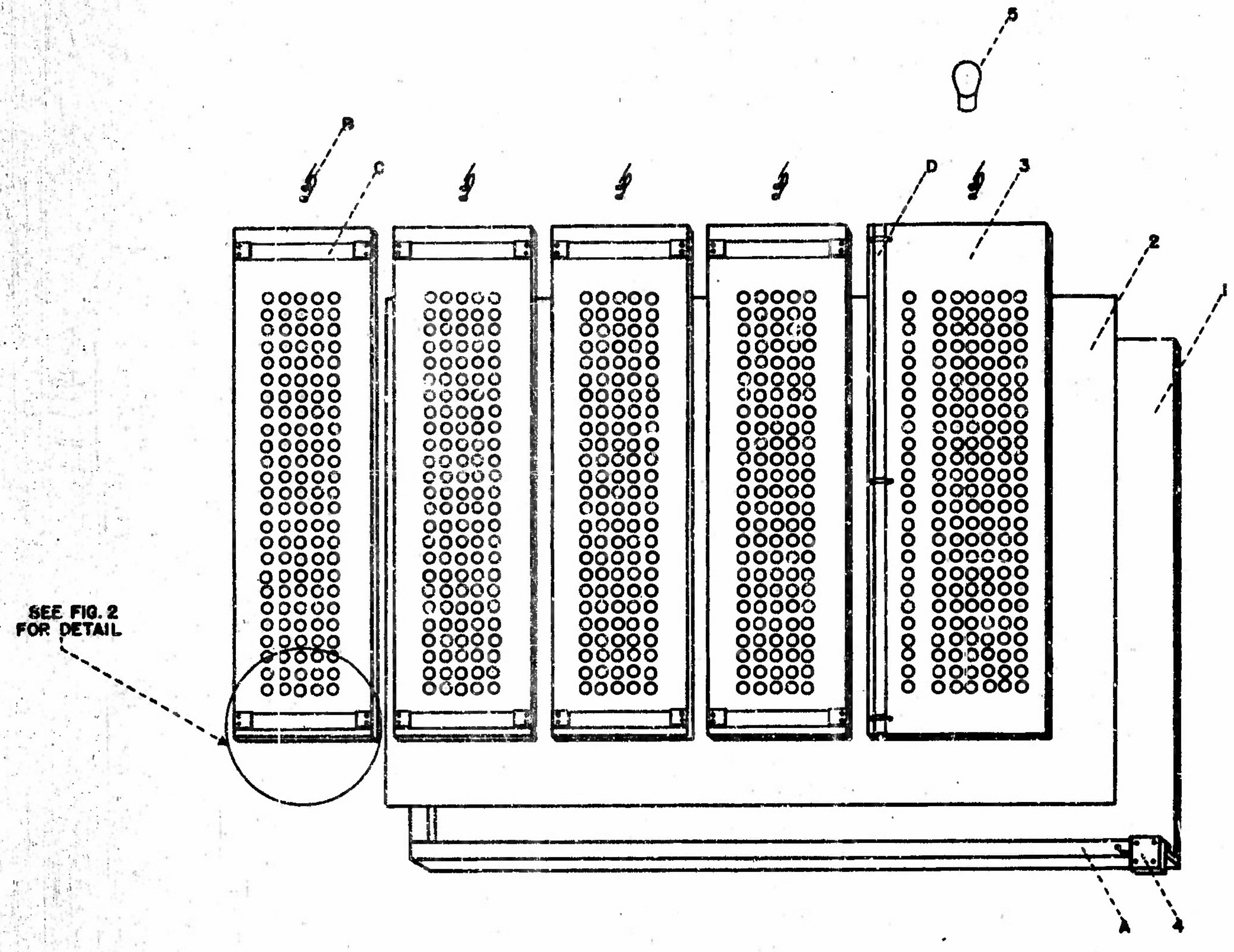

FIG. I. DIAGRAM OF MASTS TEST FORMAT.

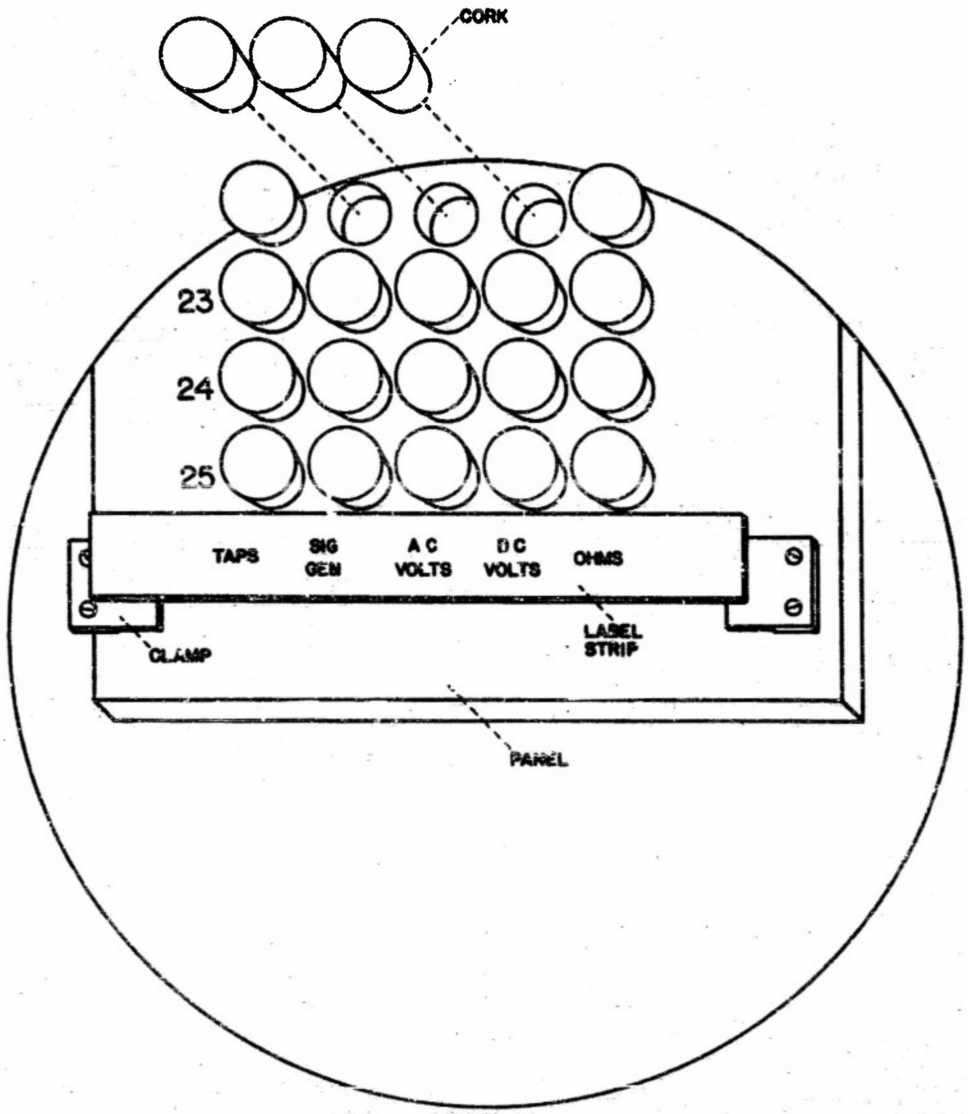

FIG. 2 DETAILS OF A TEST POINT INFORMATION PANEL.

to the five kinds of information available to the subject at each test point in the circuit. Details of the strips are shown in the expanded view in Fig. 2. Each row of corks on the four similar panels is numbered consecutively from 1 to 100, the numbers corresponding to possible test points in the circuit.

The corks in the large panel are labeled on top with the letter and number identifying a component, including major leads, in the circuit being used as the context for a problem. The first column in this panel is for "Vary" information - that which would be obtained from varying front panel controls and screwdriver adjustments. The other six columns in the panel are for the answers to the problems. These columns are labeled "Substitute New Component." For any particular problem, one of the corks in the answer section corresponds to the component in the circuit which caused the malfunction. Under it is printed the phrase "Gear Normal." The spaces under the other corks in the section are left blank.

To facilitate locating them, the corks in the answer section are grouped in rows labeled with the names of the stages in the circuit. The strip (D) is fastened along the edge of the section and carries these stage labels. It and the other labels (C) can be changed when different circuits or different test instruments are represented.

All of the corks can be removed and replaced readily. They serve to conceal problem information; the response of removing and replacing a cork corresponds to using test instruments, varying front panel controls, making screwdriver adjustments, or substituting new components in the actual equipment. Numbers (4) and (5) are the toggle switch and red warning light, respectively. They are the

chief features of a time delay circuit.[5]

B. The Subject Matter of the Test

As a symbolic representation of a trouble shooting situation, the MASTS Test is based on actual equipment. Two circuits were chosen, both available in the Philco Training Set (Plate II), a superheterodyne radio receiver and a radar sweep generator circuit. The Philco equipment is relatively portable and embodies general principles which are found in more complicated electronic systems. However, other circuits could be used for the test. The accessibility and relative simplicity of the Philco chassis facilitated the preliminary work which was necessary to establish the information pools for each problem, and to study the characteristics of trouble shooting problems.

One of the features of the test was to be its realism. The problem information was an important consideration, since it either could be "faked" or it could be obtained by putting faulty components in the equipment and using test instruments at test points to get empirical measures of the effects of the faults on the rest of the circuit. An appraisal of possibilities indicated that estimating or computing the values for the test points would be a questionable procedure. It might have resulted in lists of theoretical values, but these would have had important deviations from those a technician might obtain for himself when using test instruments.

Therefore, the decision was made to get the problem information by empirical means. Correct schematics of the two circuits were drawn. Test points were selected to represent points in all the circuit stages

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[5] This is part of a system which was devised to reproduce some of the effect the effort involved in removal and replacement of a component in actual gear has on the technician's willingness to do so until he feels it is necessary. This task acts as a deterrent to excessive removals. In the MASTS Test, the subject is given a certain amount of time to solve each problem. To prevent him from doing so by merely lifting all the corks in the answer section of the large panel, he is required to perform the following sequence of operations before he removes a cork there: push toggle switch (4) which turns on the red warning light and activates a timer (not shown in the drawing); wait thirty seconds for the timer to turn the red light off; when it goes off he can remove the cork but must repeat the sequence before another removal in that section.

at which a technician might want to sample information. There were approximately 90 such test points in each circuit. Next, the kinds of readings to take were chosen, keeping in mind the test instruments ETs commonly use. For the radio receiver these were DC volts, AC volts, ohms, signal injection and taps. For the radar circuit they were waveforms, DC volts, AC volts, and ohms. Each of these kinds of readings were made at each test point in the appropriate circuit, which resulted in from 340 to 425 readings per problem.

This procedure resulted in empirical information which was realistic, containing as it did all the minor fluctuations due to the characteristics of the test instruments and the equipment.

Prior to this work, it was necessary to select the trouble shooting problems. The initial selection was made to sample each important stage in each circuit, and each common type of failure of each type of component. As the readings were taken, some problems which had been chosen proved to be unsuitable. Some faulty components made too little difference in the operation of the equipment.[6] Certain problems had key sensory cues which could not be adequately represented symbolically. Interacting faults had to be omitted because of the difficulties inherent in representation of their symptoms and cues. The final selection includes twelve radio receiver problems and twelve radar problems. These were divided into two equal groups, to provide two sets of problems, either of which could be used in the MASTS Test. The two sets were matched on the basis of their

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[6] Another example of the divergence between the theoretical conception of a circuit and its physical translation.

electronic characteristics.

At present, then, the MASTS Test has two more or less equivalent forms so far as subject matter is concerned. In each there are six receiver problems and six radar problems. All of the information for each of these problems, except initial symptoms and supplementary reference material about the normal condition of the circuit, is on the problem sheets. This supplementary reference material, consisting of a schematic with the test point numbers, instructions to the subject, normal plate voltages, and values of major components in the circuits, is in a separate booklet.

C. Problem Information

The procedures used for getting the problem information deserve some comment, since it was necessary to devise standard methods for applying the test instruments, and to construct scales for some of the non-discrete readings.

The chief problem involved was to sample adequately the very large amount of information that could be obtained from the equipment. This was accomplished by three steps: (1) test points were carefully selected to provide a thorough coverage of the circuit; (2) test instruments were applied between a test point and common ground, never between two test points; and (3) only common information sampling procedures which could be represented symbolically were used.

Taking the AC voltage, DC voltage and resistance measurements was a relatively simple operation. First, the equipment was put in normal operating condition and these measures were taken at all test points to provide a standard with which to compare the problem readings. These

"normal" readings were taken more than once, and at different times, to correct for scale reading error and minor current fluctuations. Then, each problem in turn was put into the equipment, and measurements were made. Wherever the fault had caused a change in values, these were checked very carefully. They were compared with the normal values and then were taken again to make sure that the differences were due to the fault and not to measurement error.

The waveforms, the signal injections, and the information obtained from tapping a point with a screwdriver were special problems. The waveforms were taken with a high quality 5" laboratory type oscilloscope. They were drawn on black paper in white wax pencil. Later, each drawing was carefully checked by direct comparison with the oscilloscope waveform again. The sweep frequency and vertical gain settings of the oscilloscope were recorded as part of the waveform information.

The receiver outputs derived from the use of the signal generator and from tapping on various test points in the radio receiver with a screwdriver were auditory cues difficult to symbolize. The information obtained from tapping was included because technicians often use a screwdriver or finger to tap key points, such as grids, in the audio section of a radio receiver, as a crude but effective method of signal tracing. The signal generator was used in the way ETs generally use it; the signal was injected at a test point and the audible effects were noted at the speaker of the radio. Since the intensity of the sound in the speaker produced by both tapping and the use of the signal generator is the important cue, a four-point

scale was devised to describe the range of intensities. Each point on the scale was labeled with a short descriptive phrase or word: (1) absent, (2) weak tone, (3) loud tone, (4) very loud tone. Tapping produces a popping noise, so the word "pop" was substituted for tone to describe the intensity of this noise.

This system has proven to be reasonably effective, although it can be improved for subsequent uses of the MASTS Test. The signal generator, in particular, needs a more accurate scale which will indicate the output of the signal generator and the output intensity at the radio receiver speaker.

Information from varying front panel controls and screwdriver adjustments represented another coding problem. The important cues from these operations generally come from observation of the output while the control is being varied. Consequently, it was necessary to devise some means of representing the variation in output through the range of the control variation, and also to indicate the position of the control in the problem. For the radio circuit, the coding system used to represent volume changes is shown in Fig. 3. Short verbal statements were used for the radar circuit.

Referring to Fig. 3, I shows the system used for variable resistors, such as gain controls. Line 1 represents the range through which the control could be turned, from left to right. Line 2 represents the speaker volume at any particular point in this range, and the triangle (3) represents the relative position of the control when the problem readings were taken.

I-A, I-B, I-C are examples of how this system was used. I-A shows

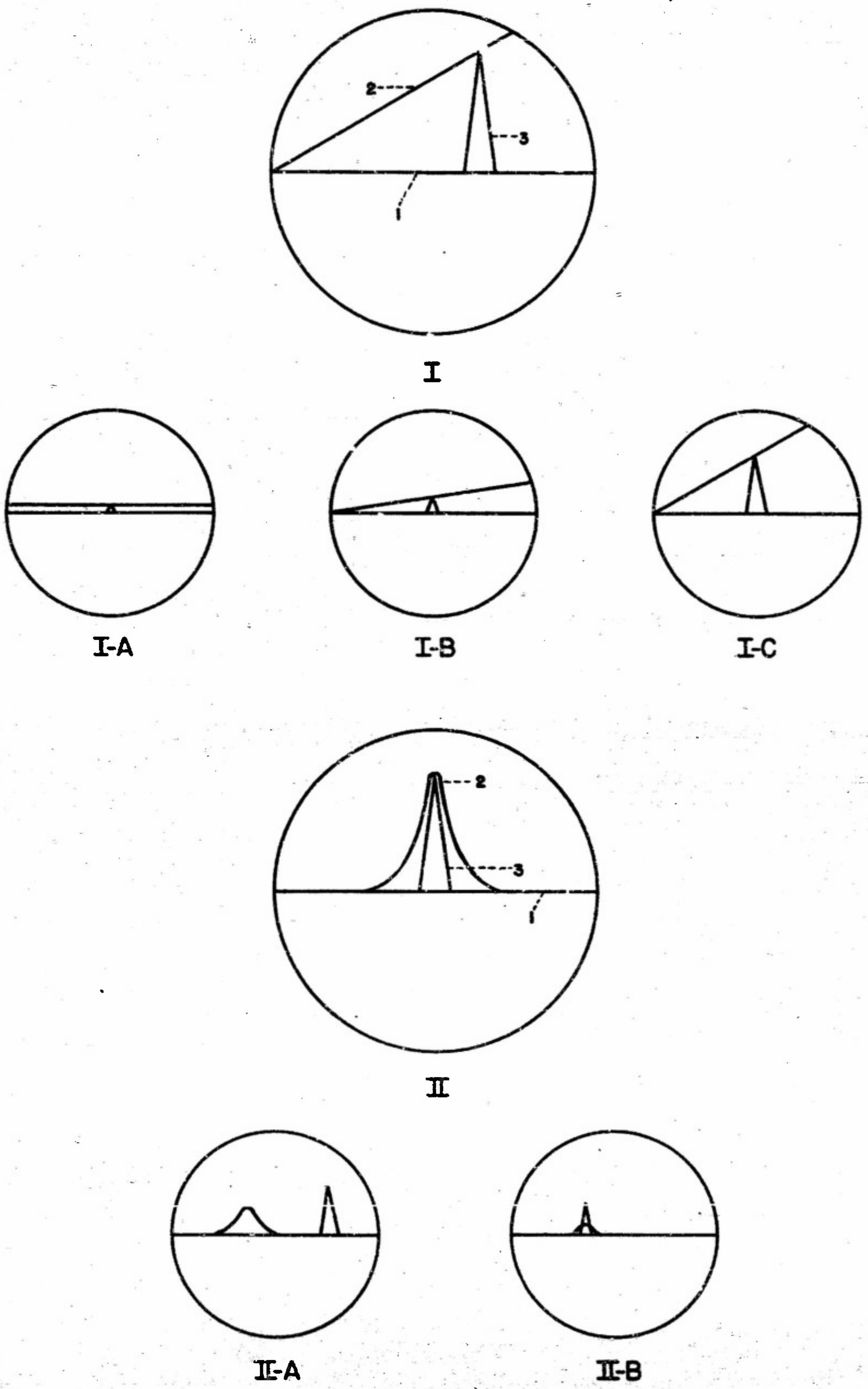

FIG. 3. CODING SYSTEM FOR INFORMATION FROM VARIABLE RESISTORS AND CAPACITORS.

that varying the control will cause no increase or decrease in volume. I-B shows a moderate increase in volume when the control is turned to the right, and I-C shows a large increase.

II shows the system used for variable capacitors. Line 1 is the range of variability; 2 shows the relative position of the control when the problem readings were taken, and 3 shows the location of the signal peak in relation to the range of the control and its position in the problem.

Again, II-A and II-B are examples of how this system was used. II-A shows a detuned tank; the trimmer is out of adjustment. II-B shows a very small signal peak at the control position, but the only peak in its range of adjustment.

This coding system was used to represent problem information only. It never showed the effects of varying the control in a normal system, which is consistent with the rest of the problem information.

D. Administration of the Test

The novelty of the test situation, and the relative complexity of the behavior it was designed to measure, requires that the subject clearly understand his role before he starts. Instructions have been written for the subjects to read. They describe the test format briefly and explain the basis of the problem information, emphasizing its empirical nature. In addition, the test administrator demonstrates the important features of the test: the use of the information and answer sections, the corks, and the red warning light. Finally, a warm-up problem is given the subject to make doubly sure

he understands the test. Currently, each problem has a twenty minute time limit.

At the beginning of the problem, the subject is given a card with a list of symptoms. He is given a schematic, and can refer to the booklet of supplementary information; component values, and normal plate voltages. He can sample information at any point he chooses and can remove and replace as many components as he chooses, if he is willing to spend thirty seconds of time for each component checked.[7] In other words, the subject has to find his own path to solution of the problem. If he is successful, he locates the cork corresponding to the faulty component and reads under it "Gear Normal," signifying that replacement of this component with a new one corrects the malfunction and ends the problem.

IV. SCORING PARAMETERS

A scoring system depends upon the definition of a criterion of success and the relationship to that criterion of the behavioral referents recorded during the test, which are assigned numerical values. This fact means that there usually are several alternative ways to score

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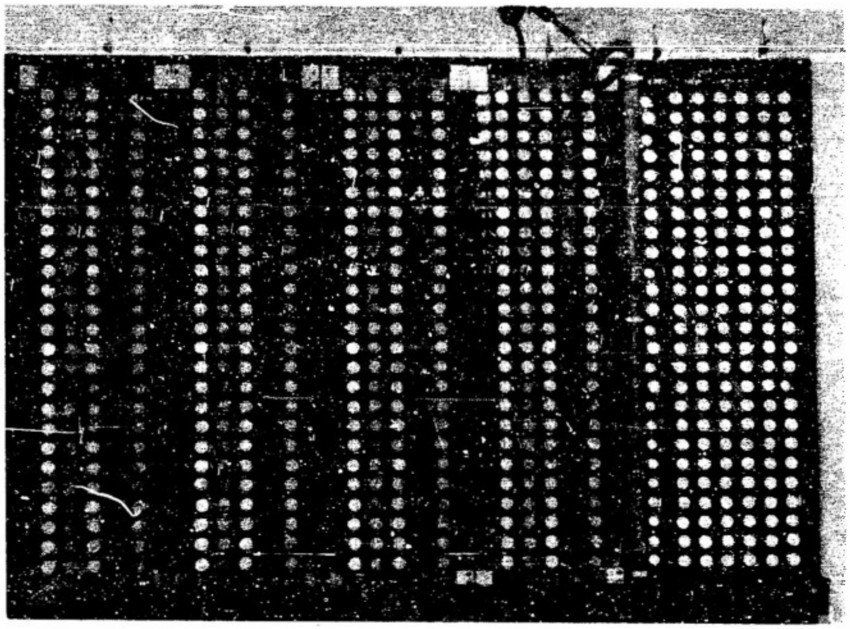
[7] Thirty seconds may appear to be slight deterrent to random guessing in the answer section. Actually, the required sequence of operations for turning the light on and off tends to break up the subject's response pattern and force him to concentrate on a manipulative activity. The light interrupts the subject at a point where his subjective need to finish the task is greatest; just before he can obtain knowledge of results. Under these circumstances, thirty seconds seems like five minutes. Furthermore, there are such a large number of components in the answer section that only a small fraction could be checked in the twenty minute time limit per problem, even if that were all the subject did.



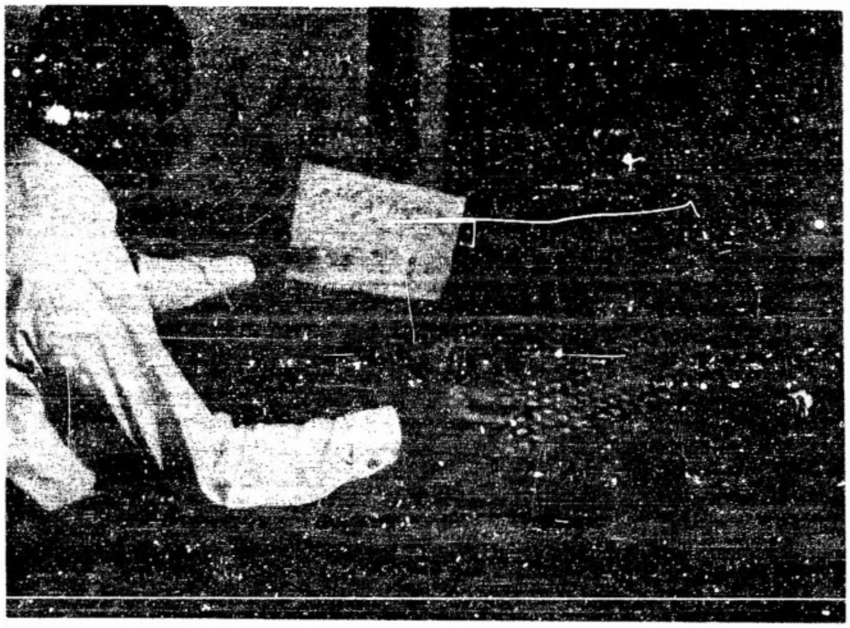


PLATE I. PHOTOGRAPHS SHOWING THE STRUCTURAL FEATURES AND THE USE OF THE MASTS TEST.

any test. During the development of the MASTS Test, this has been kept in mind, and the basic response records from which several scoring systems could be derived are being obtained in its preliminary tryout.

So far as scoring is concerned, there are two general ways of treating problems in the test; as items or as subtests. In this section, these two alternatives will be discussed, and the preliminary scoring objectives will be listed.

A. Problems as Items

Failures in electronic equipment are a heterogeneous class of problem situations. The distinguishing characteristics of this class are: (a) the output of an electronic system deteriorates below tolerance limits; (b) this divergence is reflected in output symptoms which may be necessary but seldom are sufficient information to locate the cause; and (c) finding the cause of the divergence usually requires an examination of the interacting functions in the system between input and output.

Heterogeneity results from the differences among trouble shooting problems with respect to number, variety, and discriminability of output symptoms; number, variety and discriminability of cues to be found between input and output; the specificity of the relationship between this information and probable causes; and the kinds of events which are causes of the trouble. These differences make some problems very difficult to solve, some easy. There are, of course, other factors which influence difficulty level, such as complexity of the circuit.

Ideally, it should be possible to predict the difficulty level of a problem from its discriminable electronic characteristics, and a test emphasizing either speed or power could be constructed. However, at the time the problems for the MASTS Test were selected, the knowledge necessary for such predictions was lacking. The relationship between what might be called the psychological characteristics of a problem and its electronic characteristics was not known. Certain logical generalizations are possible, but there obviously are so many determinants of problem difficulty that this kind of generalizing becomes dangerous unless checked empirically.

The selected problems were pretested on a small sample of subjects who had been ETs, and the results were used as a rough indicator of the difficulty of each problem. It is expected that data from the preliminary administration of the test at the Long Beach Naval Shipyard will provide more information about the relationship between these two categories of problem characteristics.

When trouble shooting problems are treated as items in a test, essentially what is scored is the end product of the subject's performance. He solves a problem or he fails to solve it under the conditions specified by the test instructions. This fact can be noted and he can be scored Right or Wrong on that particular problem. Whether 0 and 1, or some other weight is used, the essential fact is that this procedure emphasizes results rather than technique. It conforms to a practical criterion of a good trouble shooter as a man who finds the cause of an equipment malfunction.

B. Problems as Subtests

While a practical, working definition of good trouble shooting emphasizes results, obviously there must be reliable differences between the behavior of technicians who consistently fail and those who consistently succeed. We must assume the end is a product of the means. In twenty minutes, a subject's behavior should reveal some valid information about his skill in trouble shooting. The problem is to identify and score the elements in this behavior which discriminate among subjects with respect to this skill. Unfortunately, most of the presumably critical steps in problem solving are not directly observable. Evaluation of them necessarily is indirect. Furthermore, the nature of trouble shooting behavior, as it is conceived of here, precludes the use of a checklist type of procedure which assumes there is one best sequence of pre-solution steps, or one best pre-solution path.

Excluding the traditional evaluative techniques which employ an observer to watch and to make subjective judgments about a performance, there appear to be two alternatives to scoring within-problems variance. Either each problem can be divided into subgoals or some method of evaluating the subject's technique can be found.

The first alternative essentially makes several items of each problem. For example, a subject could be given credit for localizing the fault to the correct stage, and additional credit for localizing it to a specific component. The second alternative is based on the assumption that there are good and bad trouble shooting techniques. Some preliminary analyses have indicated the potentialities for development of a response evaluation system. By use of a schematic of

the circuit in conjunction with the response records, it is possible to reconstruct the subject's path from beginning of the problem to its end. Path plots of several successful and unsuccessful subject's responses on the same problem have indicated that the latter tend to repeat measurements at the same point more frequently, may not definitely localize a fault to a stage before working extensively within a stage, and tend to get into cul-de-sacs from which they cannot extricate themselves. These trends, noted from a few records, will need support from a more extensive analysis before they can be useful as scoring discriminanda.

Another preliminary analysis of the response records has been along the same lines. While the subject's solution path is being plotted, judgments of fruitfulness and unfruitfulness were applied to each response. The totals were used for computing the ratio between the total number of responses a subject made and the number of responses which were fruitful in moving him closer to the solution. This analysis suggested that such a ratio could be a valid pre-solution measure of trouble shooting skill. It emphasizes the efficiency of the subject's technique. Unfortunately, its computation is somewhat laborious, and the judgments by which the responses are categorized require more information for their basis than presently is available.

It is anticipated that these and similar analyses of the response records can be done more extensively after the first administration of the MASTS Test has been completed.

C. Preliminary Scoring Objectives

During the initial administration of the test at Long Beach, the following performance records were obtained from each subject: (a) time

required to solve each problem, (b) number of problems solved within the twenty minutes per problem limit, (c) complete response records of pre-solution behavior.[8]

The fewest possible restrictions were to be imposed on the subject's behavior, other than that inherent in the trouble shooting situation. Theoretically, every problem selected could be solved by every subject if he persisted long enough. If nothing else, he might rebuild the circuit a component at a time.

However, for practical administrative reasons, it was necessary to set a time limit on each problem. Twenty minutes was selected because pretesting suggested that the distribution of solution times is bimodal; either a subject solves a problem in a relatively straightforward fashion or he becomes confused and uses up a proportionately much larger amount of time testing the wrong hypotheses or fumbling for cues which will put him on the way to a solution. The twenty minute limit was chosen to cut off the second mode of the distribution.

It is expected that the three categories of data will permit use of simple and objective scoring procedures which treat problems as items, and also will provide the foundation for deriving potentially more discriminating scoring systems, based on problems as subtests.

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[8] See the appendix for a sample response record.

V. COMPARISON OF THE MASTS TEST WITH A JOB-SAMPLE TEST

Proficiency measures should predict on-the-job performance or some aspect of it. There may be many elements in the performance itself which are non-discriminating, so far as ranking the performers is concerned. At any one time, the on-the-job situation may not be representative of the tasks a technician has to perform over a long period of time. A proficiency measure abstracts what are believed to be critical elements from the on-the-job situation. Performance tests simulate this situation or elements of it. Paper-and-pencil tests usually measure knowledge related to the performance, although it often is not a sufficient condition for the successful occurrence of that performance.

Conventional job-sample performance tests and paper-and-pencil tests may be placed at different levels on a dimension of abstraction from the on-the-job situation. The MASTS Test was developed to be at a level of abstraction intermediate between these two conventional formats. Ideally, it should possess much of the administrative convenience and economy of the paper-and-pencil type of test, and evoke performance from the subjects comparable to that elicited by a conventional job-sample performance test.

In this section, the MASTS Test is compared with the job-sample test from which it was derived.

A. Behavioral Structuring in the Trouble Shooting Situation

The essentials of this situation have been characterized in Sec-

tion II. It is conceived of as presenting the technician with a type of complex problem to solve. On the job, he is free to use certain methods and to proceed in certain ways. He is not free to use some other methods or to proceed in some other ways. These conditions structure his behavior; they impose restrictions and limitations on it. The resulting performance is a product of the interaction of the individual with the situation. The major structuring conditions in the on-the-job trouble shooting situation may be listed as: (1) the design characteristics of the equipment; (2) the type of test instruments and supplementary information available; (3) the regulations concerning corrective maintenance imposed on the ET; and (4) the attitudes of others in the situation toward the ET. These factors will influence the availability and usefulness of output symptoms, the information getting procedures the technician uses and the choice of points at which to apply them, the degree to which he becomes ego-involved in the task, the length of time he will work at it, etc.

The point being emphasized here is that his performance is influenced by the total situation and that <u>any</u> proficiency measure must inevitably leave out some of the behavioral structuring conditions in the on-the-job situation.

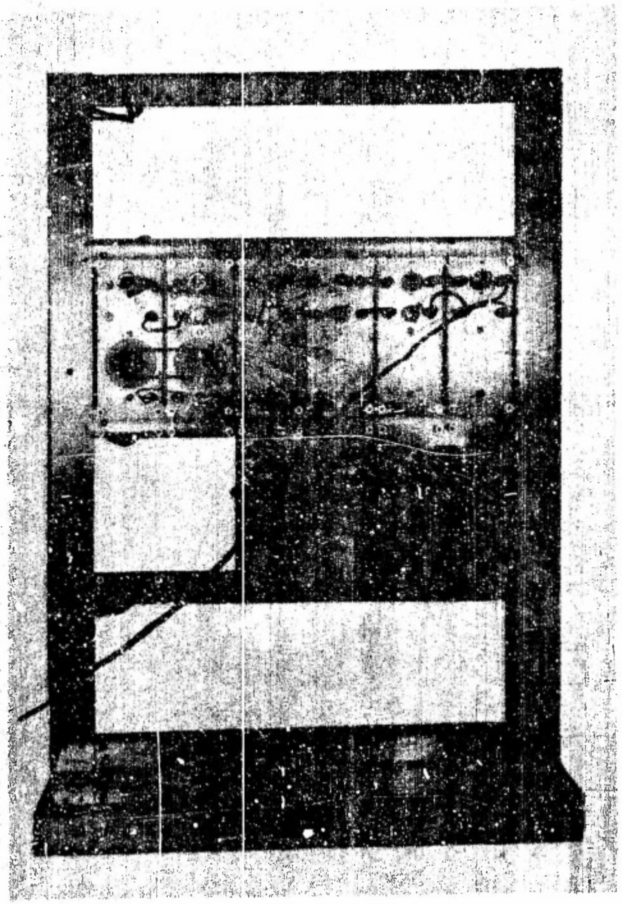
A job-sample performance test was constructed as a progenitor of the <u>MASTS</u> Test. It utilizes the same problems, test instruments, instructions, scoring and response record system. The equipment used in the test is the Philco Training Set (Plate II). The design characteristics of this device differ from fleet equipment in several respects. The Philco gear has interchangeable chassis which corre-

spond to circuit stages. The components in these chassis generally are very accessible and easily identified from the schematic. With the exception of large transformers and some potentiometers, all the components are mounted on removable strips. This feature tends to reduce the effect of inaccessibility of components and difficulty of their removal on trouble shooting behavior. It also reduces the time the technician otherwise would have to spend in circuit tracing and in hunting for a particularly obscure component.

The circuits in the Philco gear are considerably simpler than most of those in fleet gear. This results in a smaller total functional organization to work with. There are no physical units larger than a stage or a power supply.

These differences are being pointed out to make it clear that the development of the MASTS Test has been a methodological problem up to now. It is expected to resemble most closely this job-sample test, based on Philco gear, not any specific trouble shooting situation in the fleet. If the format of the test proves worthwhile, its specific subject matter can be extended to fleet equipment where necessary. For the initial developmental work, the simpler, more available equipment was chosen in the interests of economy and portability.

However, it should be emphasized that the Philco job-sample test still requires the subject to perform the essential trouble shooting steps discussed in Section II, and summarized here: (a) choose information-getting devices and procedures, (b) select points in the circuit at which to sample information, (c) use information-getting devices and procedures correctly, (d) perform the discrimination of



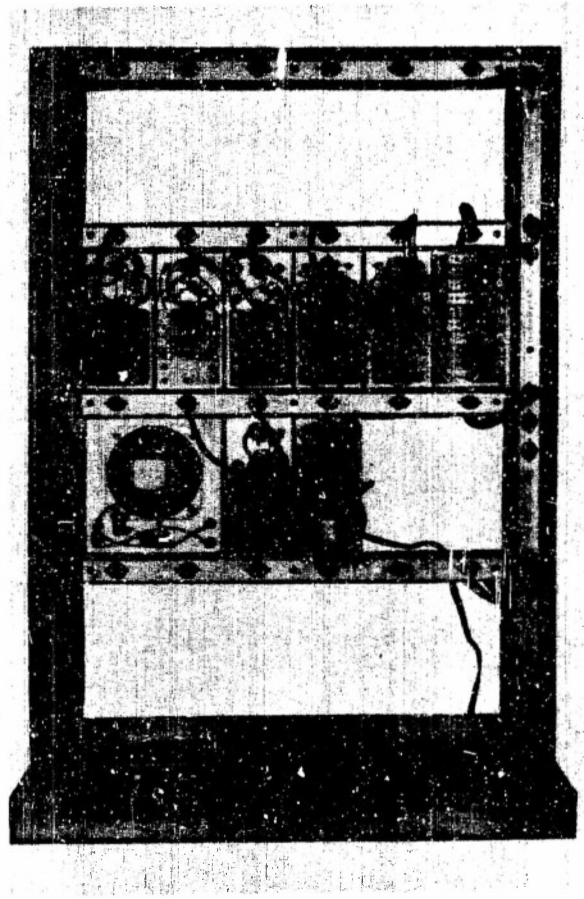
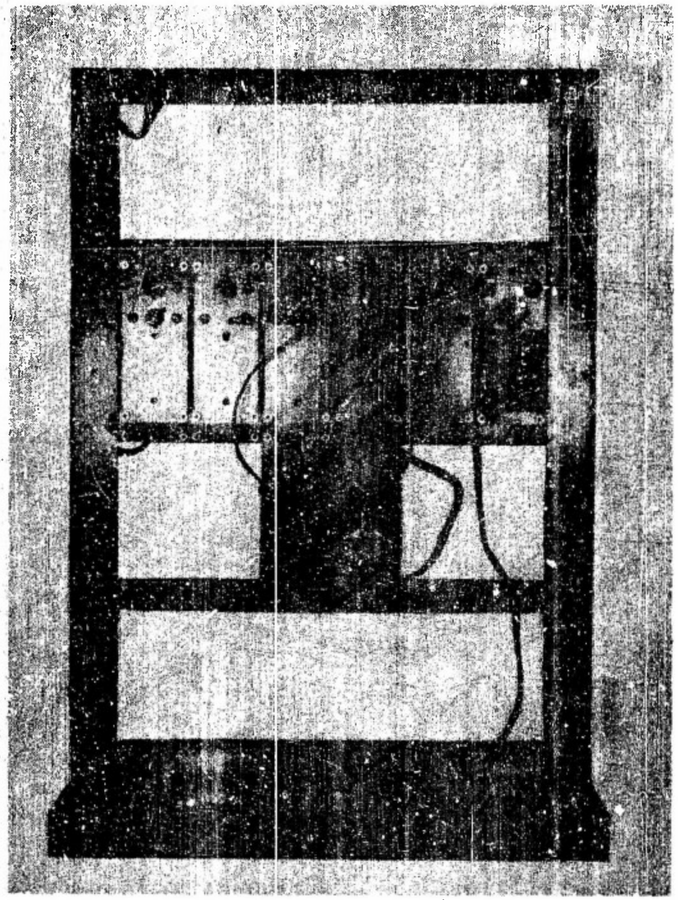


PLATE 2. PHOTOGRAPHS OF THE PHILCO ELECTRONICS TRAINING SET.
A. SUPERHETERODYNE RADIO RECEIVER.



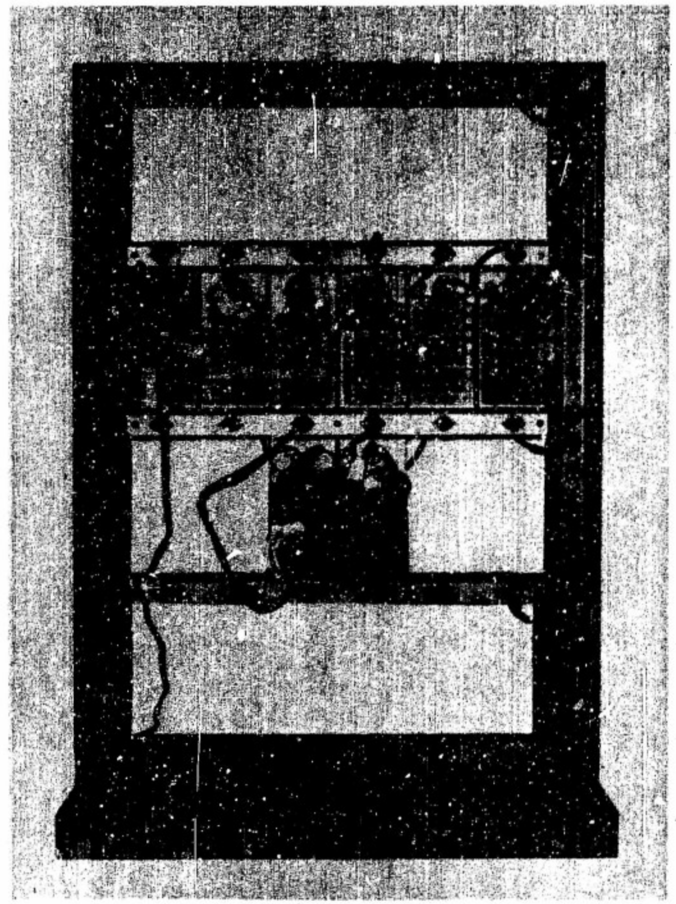


PLATE 2. PHOTOGRAPHS OF THE PHILCO ELECTRONICS TRAINING SET.
B. SIMPLIFIED RADAR SYSTEM.

"usual" or "unusual" for each bit of information collected, (e) integrate the information into a cause-effect frame of reference, (f) eliminate possible causes and check probable causes of the malfunction.

B. Behavioral Structuring in the MASTS Test

The absence of equipment and test instruments is the chief source of differences between the general structuring conditions of this test, and those of the job-sample test discussed above. Adequate representation of the problems and problem information required a coding system and a standard procedure for obtaining the information to be coded. This symbolic representation of the problems had its own implications for channeling the subject's behavior: (a) it eliminated the variance inherent in actual manipulation of test instruments; setting them on the proper scale, connecting them to the circuit correctly, and reading their meters correctly; (b) it somewhat restricted the kind and amount of problem information available to the subject (e.g., no readings between test points); (c) it made getting information much easier, since lifting a cork is simpler than using test instruments; (d) it eliminated the problem cues ordinarily available to the unaided senses; (e) it eliminated the necessity to relate a schematic to the physical arrangement of components in the equipment; and (f) it eliminated the danger of electric shock to the subject.

Inasmuch as response records have been taken during administration of both the MASTS Test and the job-sample test, it will be possible to study the effects of the different structuring conditions in the two test situations on subject performance and on problem difficulty. The response records are expected to be as important a

source of information about these effects as will be intercorrelations of scores from the two tests. The results of these comparisons will be presented in a subsequent report.

VI. APPENDIX

SAMPLE RESPONSE RECORD

The sample performance record reproduced below was recorded while a subject solved a radio receiver problem in the MASTS Test. The fault consisted of a shorted by-pass capacitor in the AVC lead, diode detector stage. The subject was an ET - 2nd.

The left side of the sample contains the response record as it was originally written in code. The right side contains the translation of the code. The column heading "Step" refers to the order of the subject's responses. "Time" was recorded to the nearest minute. "Location" refers to the test point of component involved in the subject's response. The column headed "Action" contains the code numbers for the different kinds of information a subject gets from the test. The word "Action" is used because the information is categorized by the information-sampling devices and processes which produced it.

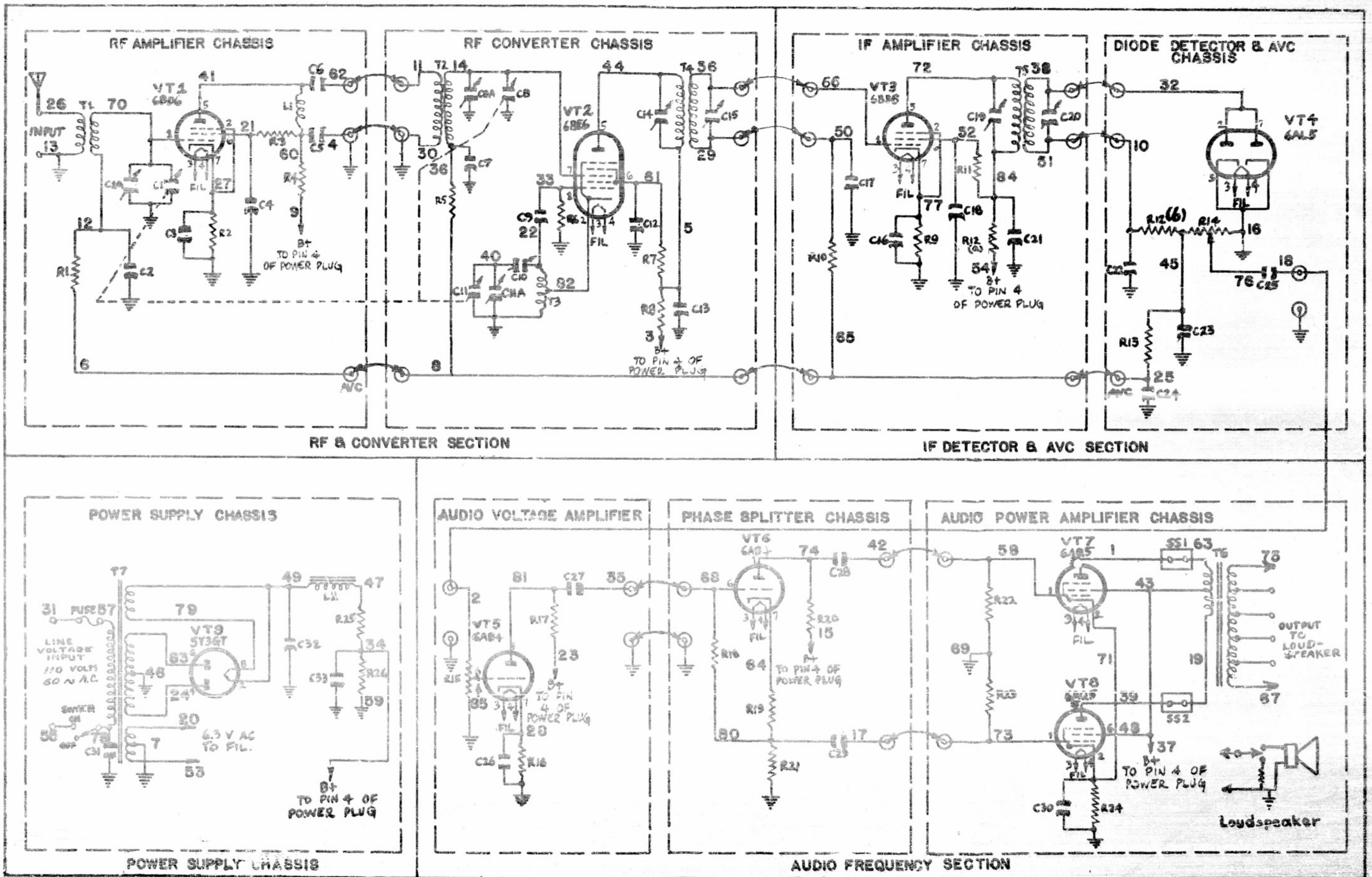
Response Record

Step	Time	Location	Action	Translation
1	0538	39	12	Injected signal at plate of tube in first side of audio power amplifier.
2	38	1	12	Injected signal at plate of tube in second side of the audio power amplifier.
3	38	73	12	Injected signal at grid of tube in first side of audio power amplifier.
4	38	58	12	Injected signal at grid of tube in second side of audio power amplifier.
5	38	74	12	Injected signal at plate of phase splitter tube.
6	39	68	12	Injected signal at grid of phase splitter tube.
7	39	81	12	Injected signal at plate of audio voltage amplifier tube.
8	39	85	12	Injected signal at grid of audio voltage amplifier tube.
9	39	32	12	Injected signal at plates of diode detector tube.
10	40	16	12	Injected signal at cathodes of diode detector tube.
11	40	18	15	Measured DC volts at output of diode detector.
12	40	32	14	Measured AC volts at plates of diode detector tube.
13	40	32	15	Measured DC volts at plates of diode detector tube.
14	40	72	14	Measured AC volts at plate of IF amplifier tube.

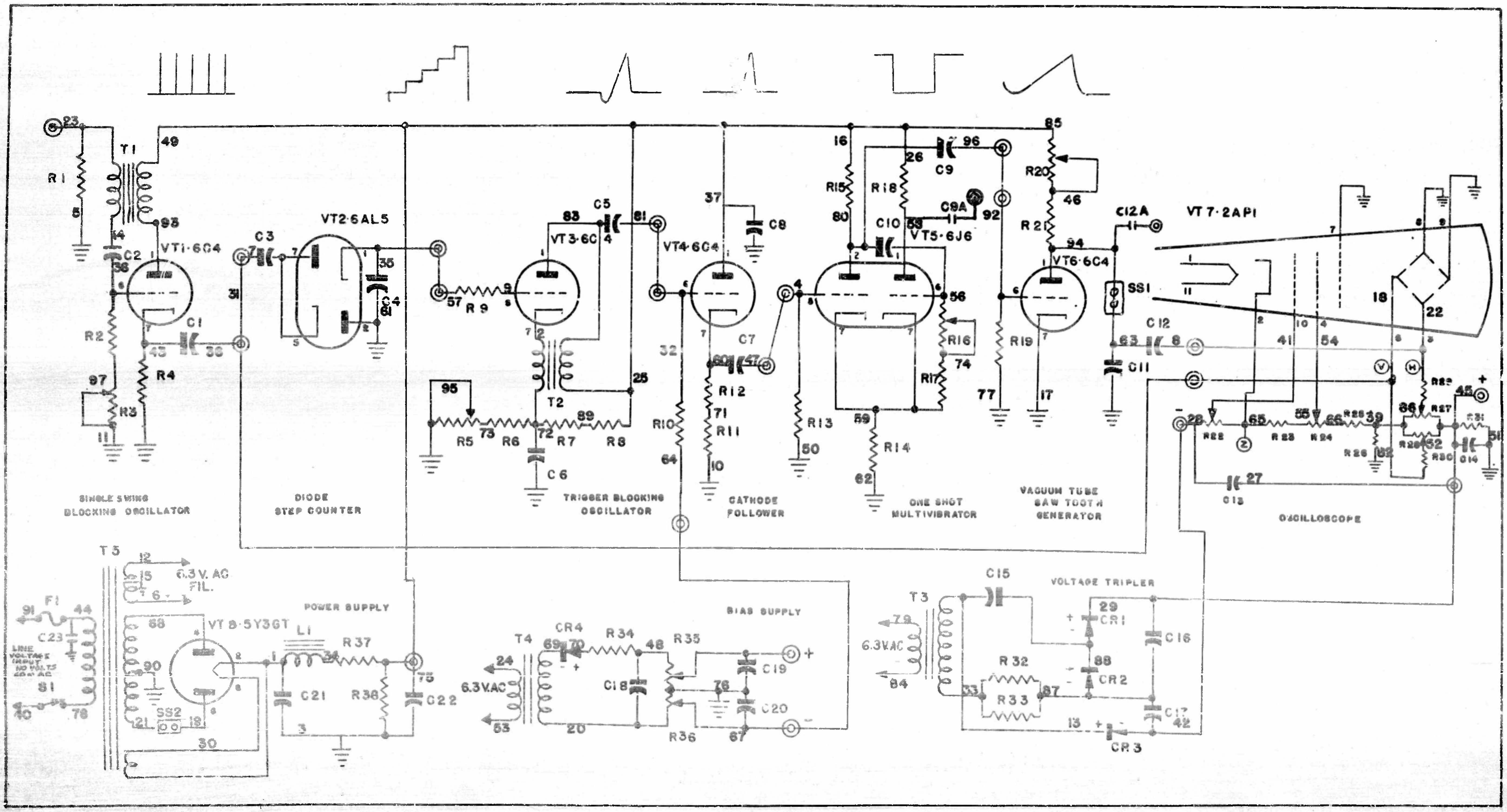
Response Record (continued)

Step	Time	Location	Action	Translation
15	0541	72	15	Measured DC volts at plate of IF amplifier tube.
16	41	52	14	Measured AC volts at screen grid of IF amplifier tube.
17	41	16	13	Measured ohms (DC resistance) at cathodes of diode detector tube.
18	41	18	13	Measured ohms (DC resistance) at coupling capacitor between diode detector and audio voltage amplifier.
19	41	76	13	Measured ohms (DC resistance) on the other side of same coupling capacitor.
20	42	45	13	Measured ohms (DC resistance) at AVC lead input, diode detector.
21	42	C - 23	6-8	Removed by-pass capacitor (C - 23) and replaced with a new component. (This solved the problem.)

Note.—The order of the stages, from input to output, in this particular circuit is: RF amplifier, RF converter, IF amplifier, diode detector and AVC, audio voltage amplifier, phase splitter, and audio power amplifier.



BASIC RADIO RECEIVER CIRCUIT DIAGRAM.



BASIC RADAR SWEEP GENERATOR CIRCUIT DIAGRAM.